DRAFT FEASIBILITY STUDY REPORT APPENDIX B: HYDRODYNAMIC CAP MODELING

SAN JACINTO RIVER WASTE PITS SUPERFUND SITE

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LIST OF ACRONYMS AND ABBREVIATIONS

ACES	Automated Coastal Engineering System
Anchor QEA	Anchor QEA, LLC
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
D_{50}	median diameter
D_{100}	maximum diameter
EFDC	Environmental Fluid Dynamics Code
FS	Feasibility Study
H:V	horizontal to vertical
I-10	Interstate 10
mph	miles per hour
psf	pounds per square foot
RAWP	Removal Action Work Plan
S_f	safety factor
Site	San Jacinto River Waste Pits Superfund Site
SJRF	San Jacinto River Fleet
TCRA	Time Critical Removal Action
USACE	U.S. Army Corps of Engineers
USEPA	U.S. Environmental Protection Agency

1 INTRODUCTION

This appendix to the Draft Feasibility Study (FS) Report for the San Jacinto River Waste Pits Superfund Site (Site) presents the results of the hydrodynamic evaluation of a permanent cap considered as part of the FS. The permanent cap is included in remedial Alternatives 3, 4, and 5 described in the main text of the Draft FS. Specifically, this appendix documents the following:

- The design rock size for a permanent cap, focusing on the factor of safety for armor rock on slopes in the wave-breaking (i.e., surf) zone in the area of the impoundments located north of I-10 (Northern Impoundments) where a Time Critical Removal Action (TCRA) has already been completed (TCRA Site)
- The effect of varying assumptions for the design storm event magnitude on predicted stable armor rock sizes

1.1 Background

The TCRA included the design and installation of an armored cap over the TCRA Site. The TCRA cap was designed to provide immediate containment of the materials in the former Northern Impoundments and to be compatible with a final Site remedy. As with any cap design, the factor of safety can be increased, which ultimately will reduce the potential for long-term cap maintenance needs.

Subsequent to completion of the TCRA, U.S. Environmental Protection Agency (USEPA) raised questions about the basis of design for the TCRA, specifically the protectiveness of a cap design that is based on the 100-year return interval storm, which is recommended in USEPA's contaminated sediment remediation guidance (USEPA 2005). The TCRA cap was designed considering a range of storms up to the 100-year return interval. In support of the Draft FS, additional evaluations were performed to consider a range of specific modeled events, as well as an extreme-level storm event with a 500-year return interval.

1.2 Permanent Cap

The Draft FS includes a permanent cap for several alternatives, which entails flattening the slopes of the existing TCRA cap by adding additional armor rock material to increase the factor of safety. Construction of a permanent cap would entail construction of 5 horizontal to 1 vertical (5H:1V) slopes along the central, western, and southern berms (flattening these berms from 2H:1V to 5H:1V) to increase the factor of safety in the wave-breaking zone, and flattening the submerged slopes from 2H:1V to 3H:1V to increase the factor of safety for submerged slopes.

Armor Cap D material, as described in the TCRA *Final Removal Action Work Plan* (RAWP; Anchor QEA 2010), would be used for the permanent cap. This is a natural stone material with the following estimated gradation:

- D_{100} = 15 inches
- D_{85} = 12 inches
- D_{50} = 10 inches
- D_{15} = 8 inches

1.3 Design Storm Event Evaluation

In addition to evaluating design slopes and armor size for the permanent cap, this appendix describes the analysis that was performed to evaluate the long-term protectiveness of the permanent cap under a variety of storm conditions, including several actual storms that have occurred in the vicinity of the Site. An evaluation of current velocities and stable cap grain size was performed for wind- and vessel-generated waves breaking in the surf zone, as well as for river currents during the following storm and flood scenarios:

- 5-year flood
- 10-year flood
- 25-year flood
- 50-year flood
- 100-year flood
- 500-year flood
- Hurricane Ike
- Tropical Storm Allison
- October 1994 Harris County flood

2 DESIGN AND PERFORMANCE CRITERIA

The USEPA's and U.S. Army Corps of Engineers' (USACE's) Guidance for In-Situ Subaqueous Capping of Contaminated Sediments (Palermo et al. 1998) states the following:

> *The cap component for stabilization/erosion protection has a dual function…to stabilize the contaminated sediments being capped…[and] to make the cap itself resistant to erosion.*

In addition, USEPA's Contaminated Sediment Remediation Guidance for Hazardous Waste Sites (USEPA 2005) states the following:

> *[T]he design of the erosion protection features of an in-situ cap (i.e., armor layers) should be based on the magnitude and probability of occurrence of relatively extreme erosive forces estimated at the capping site. Generally, in-situ caps should be designed to withstand forces with a probability of 0.01 per year, for example, the 100-year storm.*

The TCRA cap was designed to provide isolation of underlying sediment and protection from erosive forces in the San Jacinto River (waves and currents). The permanent cap will provide enhanced long-term protection of the underlying materials. The evaluation of the permanent cap was performed using methods developed by USEPA and USACE specifically for in situ caps. This includes the methods included in Armor Layer Design of Guidance for In Situ Subaqueous Capping of Contaminated Sediments (Maynord 1998).

In addition to the recommended 100-year storm design criterion, this appendix considers a range of storm and flood scenarios up to the 500-year storm to assess the sensitivity of the stable armor rock size to the magnitude of the storm, and to evaluate the performance of the permanent cap under these extreme scenarios.

3 WIND WAVE AND VESSEL WAKE EVALUATION

This section describes evaluations of wind-generated waves and vessel-generated wakes, both of which were used to assess the permanent cap that is described in the FS.

3.1 Wind-Generated Waves

Winds blowing across the surface of bodies of water transmit energy to the water, and waves are formed. The size of these wind-generated waves depends on the wind velocity, the length of time the wind is blowing, and the extent of open water over which it blows (i.e., the "fetch" length; USACE 1991).

The wind-generated wave evaluation performed as part of this assessment consisted of the following major components:

1. Obtaining historical wind speeds and directions near the TCRA Site
2. Conducting a statistical evaluation of wind data to estimate the various return interval wind speeds for the largest fetch distances adjacent to the TCRA Site
3. Estimating the corresponding wave height and period from the wind data

3.1.1 Wind Data Evaluation

Hourly wind measurements (speed and direction) from 1973 through July 2012 were obtained from George Bush Intercontinental Airport in Houston, Texas. A wind rose diagram for the data, illustrating how wind speed and direction are typically distributed for the TCRA Site, is shown on Figure 1. The wind data were reported in 2-minute averages every hour. As can be seen in this figure, the prevailing winds in the area are from the south and southeasterly directions, although there can be significant wind events from the north.

The methodology used to estimate wind speeds for wave prediction was consistent with that described in Part II – Chapter 2 of the USACE's Coastal Engineering Manual (USACE 2006). A statistical evaluation was performed on the maximum annual wind speeds to estimate various return interval wind speeds from the north and northwest (the two longest fetch distances that could create wind-generated waves that could impact the TCRA Site). Figure 2 shows the fetch distances from the north and northwest used in the calculation.

Five candidate probability distribution functions were fitted to the maximum 2-minute averaged annual wind speeds to develop representative wind speeds with different return periods. The candidate distribution functions evaluated were Fisher-Tippet Type I and Weibull distributions with the exponent *k* varying from 0.75 to 2.0. The return interval wind speeds used in the design were chosen from the distribution that best fit the data. Figures 3 and 4 show the plots of the computed return interval wind speeds for winds blowing from north and northwest, respectively.

3.1.2 Wave Prediction

The USACE Automated Coastal Engineering System (ACES) computer program was used to model wave growth and propagation due to winds (USACE 1992). The ACES program was developed by USACE and is an accepted worldwide reference for modeling water wave mechanics and properties. To compute the wave height for each direction, the wind speed was applied along the fetch distance shown on Figure 2 for each direction. The wave height and period were determined using the ACES Wave Prediction Module. Tables 3-1 and 3-2 summarize the results for winds from the north and northwest, respectively.

Table 3-1
Computed Significant Wave Heights and Periods for Winds Blowing from the North (0.8-mile fetch length)

Description	2-year	5-year	10-year	25-year	50-year	100-year
Wind speed (miles per hour)	26.9	33.0	37.0	42.1	45.9	49.7
Significant wave height (feet)	0.71	0.88	0.99	1.13	1.24	1.34
Wave period (seconds)	1.49	1.60	1.67	1.75	1.80	1.85

Table 3-2
Computed Significant Wave Heights and Periods for Winds Blowing from the Northwest (1.4-mile fetch length)

Description	2-year	5-year	10-year	25-year	50-year	100-year
Wind Speed (miles per hour)	29.2	34.3	37.7	41.9	45.1	48.2
Significant Wave Height (feet)	0.99	1.17	1.28	1.42	1.53	1.63
Wave Period (seconds)	1.80	1.91	1.97	2.05	2.10	2.15

Note:
In the ACES Wave Prediction Module, the 2-minute averaged wind speeds input to ACES were converted to 15-minute averaged wind speeds in the wave generation model because the wave generation process correlates to 15-minute interval wind speeds. Shorter-duration gusts are generally not sufficient for significant wave generation.

Because the estimated 100-year wind speed from the north (49.7 miles per hour [mph]) was below the maximum northerly wind speed measured (53.0 mph), a calculation of the wave height and period was performed using the maximum measured wind speed. The computed significant wave height and period for a wind speed of 53.0 mph from the north was 1.43 feet and 1.90 seconds, respectively.

Based on this evaluation, wind-generated significant wave heights could range from 0.71 to 1.63 feet.

3.2 Vessel Wake Evaluation

Waves can also be generated by a boat moving through the water. These vessel-generated waves are often referred to as wakes. An evaluation was performed to estimate the potential vessel-generated wake heights associated with the tugboats that may operate in the river near the TCRA Site, and in particular in the vicinity of the San Jacinto River Fleet (SJRF) barge fleeting operations that were established near the TCRA Site, subsequent to the original TCRA design. In the area of the TCRA Site, the limited water depth prohibits large vessels from operating close to the cap.

Based on information provided by local vessel operators, the vertical clearances of bridges limit river operations to smaller tugboats north of Interstate 10 (I-10), and the tugboats that operate in this area typically move at speeds between 2 and 4 knots (2.3 to 4.6 mph), which minimizes vessel wakes ("no wake") but allows for steerage and control. Local vessel operators also state that the largest tugboats that operate north of I-10 adjacent to the TCRA Site are typically 400- to 800-horsepower class craft. These tugboats operate in the main channel of the San Jacinto River. Based on bathymetric surveys conducted in the vicinity of the TCRA Site, there is a 26-foot-deep channel located 250 feet east of the TCRA Site, a 20-foot-deep channel located 950 feet northeast of the TCRA Site, and a 16-foot-deep channel located 1,350 feet north of the TCRA Site.

Based on a review of the river bathymetry and the location of the SJRF area, tugboats operating to support the SJRF barge activities operate in 12 to 16 feet of water approximately 430 feet or more north and northwest of the TCRA Site. In a report entitled Final Sampling and Analysis Plan for Pre-Construction Baseline Site Assessment, San Jacinto River Fleet Property, Harris County, Texas (Tolunay-Wong 2012), SJRF has proposed to install a line of pylons approximately 430 feet from the TCRA Site, physically separating SJRF operations from the TCRA Site.[1]

The TCRA Site is also marked with floating buoys located around the perimeter of the eastern cell. These buoys provide for an additional visible warning to vessel operators to minimize the potential for inadvertent vessel operations in close proximity to the cap.

The Sorensen-Weggel method (Sorensen and Weggel 1984; Weggel and Sorensen 1986) was used to estimate potential vessel wakes for tugboats. The Sorensen-Weggel method is an empirical model (developed from available laboratory and field data on vessel-generated waves) used to predict maximum wave height as a function of vessel speed, vessel geometry, water depth, and distance from the sailing line. This model is applicable to various vessel types (ranging from tugboats to large tankers), vessel speeds, and water depths. The method calculates the wave height generated at the bow of a vessel as a function of the vessel speed, distance from the sailing line, water depth, vessel displacement volume, and vessel hull geometry (i.e., vessel length and draft).

[1] Nothing contained in this appendix is intended to acknowledge that Respondents concur in the appropriateness or sufficiency of the proposed line of pylons by SJRF as a measure to address impacts from SJRF's operations.

For the vessel wake calculation, a tugboat with a length of 75 feet and a displacement of 7,800 cubic feet was used. This vessel size is typical of tugboats that can physically fit beneath the relatively low I-10 Bridge, and was selected for the design evaluation based on conversations with local marine contractors who operate tugboats in the San Jacinto River upstream of I-10. The vessels were conservatively assumed to operate 250 to 1,000 feet from the TCRA Site. Water depths used in the calculation ranged from 12 feet to 26 feet. As described above, the vessels operate at speeds from 2 to 4 knots (essentially a "no wake zone" speed). A vessel-wake calculation was performed for vessels travelling at the high end of the expected speed, 4 knots. An additional scenario was considered for vessels travelling at 8 knots—this higher speed representing a conservative case that is expected to overestimate potential wake impacts.

Table 3-3 presents a summary of the results of the vessel-generated wave evaluation.

Table 3-3
Vessel-Generated Wave Heights

Vessel Class	Water Depth (feet)	Vessel Speed (knots)	Distance from Sailing Line (feet)	Wave Height (feet)
Tugboat operating in the river channel	16	4	250	0.0
			1,000	0.0
		8	250	1.0
			1,000	0.6
	26	4	250	0.0
			1,000	0.0
		8	250	1.1
			1,000	0.7
Tugboat operating at the SJRF barge area	12	4	430	0.0
		8		0.8
	16	4	430	0.0
		8		0.8

Note:
SJRF - San Jacinto River Fleet

The results indicate that vessel wakes at the TCRA Site would be less than 1.2 feet.

In summary, wind-generated waves are estimated to be less than 1.7 feet, and vessel-generated wakes are expected to be less than 1.2 feet at the TCRA Site. The vessel wake results, combined with the wind-generated wave results, are used to evaluate required armor rock sizes in the wave-breaking zone of the permanent cap, as discussed below.

3.3 Evaluation of Armor Layer Material

Due to the amount of turbulence generated by breaking waves in the surf zone, the armor layer was modeled in the TCRA design as a rubble mound berm (i.e., a sloped berm [or revetment] consisting of rock). Armor stone for sloped berms was sized using guidance from USACE 2006 as part of the original TCRA design. The USACE guidance was used because the methodology to evaluate armor stone sizes for sediment caps presented in USEPA's design guidance (Maynord 1998) does not consider the effects of waves breaking on a cap, as would be the case for the sloped berms at the TCRA Site. The surf zone is defined as the region extending from the location where the waves begin to break to the limit of wave run-up on the shoreline slope. Within the surf zone, wave-breaking is the dominant hydrodynamic process (USACE 2006).

The ACES Rubble Mound Revetment Design Module was used to evaluate the armor stone gradation and thickness in the surf zone. The ACES methodology is based on van der Meer's (1988) paper entitled Deterministic and Probabilistic Design of Breakwater Armor Layers. The ACES method assumes that the waves would propagate and break on the slope of the armor layer. The structure was assumed to be permeable, thereby minimizing wave reflection. Stable particle sizes (i.e., armor sizes) were evaluated using the model for the proposed permanent cap slope of 5H:1V.

Revetments used for coastal protection projects are often designed allowing for some movement of the armor layer, which could necessitate maintenance over time. The revetment design methodology allows consideration of variable amounts of displacement (movement) of the armor layer. The amount of displacement considered can be categorized as follows:

- **No Displacement**: Little to no armor stone displacement due to wave energy
- **Minor Displacement**: Minimal movement (less than 5 percent) of armor stones displaced due to wave energy and potentially redistributed within or in the near vicinity of the armor layer
- **Intermediate Displacement**: Displacement ranges from moderate to severe; armor stones are expected to be displaced

The existing TCRA armor cap armor was designed for minimal movement (Anchor QEA 2010), also referred to as the "Minor Displacement" scenario in the rubble mound design guidance. The Minor Displacement scenario is the same as that applied at other Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) cap sites (e.g., Onondaga Lake Superfund Site in Syracuse, New York; Lower Fox River Superfund Site in Green Bay, Wisconsin), to ensure protectiveness.

For design of the permanent cap, the No Displacement and Minor Displacement scenarios were evaluated for slopes constructed at 5H:1V using a wave height of 1.63 feet and wave period of 2.15 seconds, the maximum wave height and wave period shown in Tables 3-1 and 3-2.

Table 3-4 presents the computed median and maximum particle sizes and acceptable ranges of layer thickness for the specific materials, based on the ACES calculation.

Table 3-4
Median (D_{50}) and Maximum (D_{100}) Particle Size and Thickness –
Significant Wave Height of 1.63 feet and Period of 2.15 Seconds –
Natural Stone Materials

	Natural Stone[1] (5H:1V)	
Particle Size/Thickness	**No Displacement (inches)**	**Minor Displacement[2,3] (inches)**
D_{50} (median particle size)	8.3	3.3
D_{100} (maximum particle size)	13.2	5.3
Range of thickness of armor layer[4]	12.5 to 17	5 to 7

Notes:
1. Assumes a unit weight of 165 pounds per cubic foot.
2. Computed using No Displacement and Minor Displacement scenarios. Note that No Displacement represents little to no movement of armor stones. Minor Displacement refers to minimal movement of the armor stones under extreme wave action. Repairs associated with such events (if any) would be handled as part of a maintenance program.
3. Minor Displacement was the design scenario for the TCRA cap armor.
4. Thickness ranges based on guidance from Maynord (1998) and USACE (1994).

The analysis shows that the Armor Cap D material (with a median particle size [D_{50}] of approximately 10 inches and a D_{100} of approximately 15 inches) would provide long-term protection at the TCRA Site. Although a factor of safety is not included specifically in the calculation, the Armor Cap D material proposed for the permanent cap is three times larger than that required under the Minor Displacement scenario; Armor Cap D also exceeds the criteria for the No Displacement scenario.

4 DESIGN STORM EVALUATION

4.1 Background

Hydrodynamic flows, particularly during high-flow events, can result in elevated water velocities and corresponding bed shear stresses, which have the potential to erode sediments. To evaluate the current velocities and stable particle size to resist these velocities, the hydrodynamic model developed as part of the TCRA design was used. The model framework, boundary conditions, development, and calibration is described in detail in RAWP Appendix I – Hydrodynamic Modeling of Anchor QEA (2010), which considered a range of design events up to the 100-year storm.

Based on inquiries from USEPA during development of the FS, the sensitivity of the cap design was assessed for additional storm events, as well as an extreme 500-year recurrence interval storm to evaluate the protectiveness of the cap design. In response to this inquiry, the model presented in Appendix I of the RAWP was updated and run for these additional scenarios.

4.2 Model Update and Simulations

The elevations of the Northern Impoundments in the model were updated based on a survey performed in April 2013, which was performed after completion of the TCRA. High-flow event hydrodynamic simulations were conducted using the updated model. Predicted current velocities within the Study Area were used to calculate the median particle diameter (D_{50}) for the cover material and to compare this diameter to the design of the permanent cap.

A wide range of events were simulated to capture the maximum velocities that may act upon the permanent cap. Using a constant upstream flow rate, the 5-year, 10-year, 25-year, 50-year, 100-year, and 500-year high-flow events were simulated (the downstream tidal elevations are described in Appendix I of Anchor QEA 2010). In addition, for comparison, measured data from the following three actual events were used in simulations with the hydrodynamic model:

- The October 1994 high-flow event (that occurred between October 11, 1994, and October 25, 1994)

- Tropical Storm Allison (that occurred between June 2, 2001, and June 16, 2001)
- Hurricane Ike (that occurred between September 7, 2008, and September 21, 2008)

The design equations to compute the stable particle size to resist river currents use depth-averaged velocities and water depth. Figure 5 shows a depiction of depth-averaged velocity in comparison to the actual distribution of velocity that would be expected in a naturally flowing system. The hydrodynamic model used in the analysis computed depth-averaged velocities. To demonstrate that the range of storm events considered cover the full range of flows that produce the maximum velocities over the TCRA Site, maximum depth-averaged velocities were computed at various locations over the Northern Impoundments. Figure 6 shows the locations where the depth-averaged velocities were computed. Figure 7 shows the maximum depth-averaged velocity for each event at each location. Figure 8 shows the corresponding water depth at the time of the maximum velocity at each location.

The results of this analysis indicate that the peak of depth-averaged velocities over the cap vary in location for each storm and flood event evaluated (Figure 7). This is primarily due to the variable topographic and bathymetric profile of the surface of the cap, and is expected because the water surface elevations in the San Jacinto River vary by storm event. As a result, the water depth, flow patterns, and scour velocities vary spatially across the Northern Impoundments for each storm event depending on the depth of the water at various locations on the cap. In many areas of the cap, as the water depth becomes deeper with larger storm events, the maximum depth averaged velocity decreases. This is especially true for the 500-year flood event.

4.3 Stable Particle-Size Calculation

The stable particle size (expressed as D_{50}) to resist the flow velocity and related bed shear stress was estimated using the Maynord method, from USEPA Guidance for In-Situ Subaqueous Capping of Contaminated Sediment – Appendix A: Armor Layer Design (Maynord 1998). The method presented in Maynord (1998) and shown below is based on the USACE's Hydraulic Design of Flood Control Channels (USACE 1994). This method uses depth-averaged velocity and flow depth to determine the stable median armor stone size (D_{50}).

$$D_{50} = S_f C_s C_v C_T C_G d \left[\left(\frac{\gamma_w}{\gamma_s - \gamma_w} \right)^{1/2} \frac{V}{\sqrt{K_1 g d}} \right]^{2.5} \qquad (1\text{-}1)$$

where:

D_{50}	=	Median particle size in feet
S_f	=	Safety factor = 1.5 from page A-6 of Maynord 1998. Per Maynord (1998), the minimum safety factory for riprap design is 1.1. A safety factor of 1.3 was used for the TCRA to be more conservative and protective. For the permanent cap, a safety factor of 1.5 is used in this calculation (a more detailed discussion is presented below).
C_s	=	Stability coefficient for incipient failure = 0.3 for angular rock (from page A-6 of Maynord 1998)
C_V	=	Velocity distribution coefficient = 1.0 (from page A-6 of Maynord 1998)
C_T	=	Blanket thickness coefficient = 1.0 for flood flows and thickness = D_{100} (from page A-6 of Maynord 1998)
C_G	=	Gradation coefficient = $(D_{85}/D_{15})^{1/3}$
D_{85}/D_{15}	=	Gradation uniformity coefficient = 1.55 for Armor Cap D material (with D_{85} = 11.8 inches and D_{15} = 7.6 inches)
d	=	Water depth in feet (from the hydrodynamic model)
γ_s	=	Unit weight of stone = 165 pounds per cubic foot
γ_w	=	Unit weight of water = 62.4 pounds per cubic foot
V	=	Maximum depth-averaged velocity in feet per second (from the hydrodynamic model)
K_1	=	Side slope correction factor = 1.0 for a slope of 5H:1V(from Plate B-39 from USACE 1994)
g	=	Acceleration due to gravity = 32.2 feet per second squared

As described above, a safety factor of 1.5 was used in the calculation. Maynord (1998) recommends a minimum safety factory for riprap design of 1.1. In addition, as described in the following from USACE (1994):

Equation 3-3 gives a rock size that should be increased to resist hydrodynamic and a variety of nonhydrodynamic-imposed forces and/or uncontrollable physical *conditions. The size increase can best be accomplished by including the safety factor, which will be a value greater than unity. The minimum safety factor is S_f = 1.1.*

For the TCRA design, the safety factor (S_f) was increased to 1.3 in Maynord's equation from the recommended 1.1 as a conservative method to account for variations in bathymetry and topography and the associated potential variations in velocities and turbulence intensity for small-scale site variations that are smaller than the two-dimensional Environmental Fluid Dynamics Code (EFDC) model grid resolution. For the permanent cap evaluation, the safety factor was further increased to 1.5.

As an example, Table 4-1 summarizes the armor stone D_{50} results based on a berm slope of 5H:1V and a safety factor of 1.5 for the maximum velocity predicted for the western berm area of the TCRA Site.

Table 4-1
Median (D_{50}) Particle Size to Resist River Currents

Location	Event	Maximum Depth-Average Velocity (feet per second)	Water Depth (feet)	D_{50} (inches)
Western berm	5-year flood	3.1	1.3	0.7
	10-year flood	1.8	1.4	0.2
	25-year flood	6.7	2.4	4.1
	50-year flood	6.4	4.6	3.1
	100-year flood	7.1	7.7	3.5
	500-year flood	3.4	18.7	0.5
	Hurricane Ike	2.2	1.4	0.3
	Tropical Storm Allison	2.5	1.2	0.4
	October 1994 high-flow event	6.5	2.5	3.7

As shown on Figure 6 and Table 4-1, the range of design storms for this evaluation is appropriate for the FS, and storms with return-intervals greater than 100-years result in lower velocities than some of the more frequent storms. The events that control the selection of the stable particle size are between the 10-year and 100-year events (depending on location).

As can be seen from these results, the Armor Cap D materials exceed the computed median (D_{50}) particle size with a conservative safety factor of 1.5. Therefore, the use of Armor Cap D materials on flatter slopes is an appropriate assumption for the design of the permanent cap.

4.4 Wave and Current Combinations

Outside of the surf zone, orbital velocities from waves combined with currents can increase bottom shear stresses. Combining extreme river current with extreme orbital velocity forces is considered to be very conservative because the probability of both extreme events occurring simultaneously is very low.

The armor stone is designed to resist forces due to waves breaking on the TCRA cap (i.e., waves would propagate and break on the western, central, or southern berm armor stone). Within the surf zone (the location where waves break), wave-breaking is the dominant hydrodynamic process (USACE 2006).

An example is provided below to evaluate the stability of Armor Cap D material for a combination of bottom velocities due to superimposed wave and current forces if the berm were to be overtopped.

The bottom shear stress due to the combination of waves and currents can be calculated using the quadratic stress law (Christoffersen and Jonsson 1985), as shown in the following equation:

$$\tau = \rho_w \left(C_{f,c} u_c^2 + C_{f,w} u_w^2 \right) \qquad (1\text{-}2)$$

where:

τ	=	Bottom shear stress
ρ_w	=	Density of water
$C_{f,c}$	=	Bottom friction coefficient for currents
u_c	=	Maximum current velocity
$C_{f,w}$	=	Bottom friction coefficient for waves
u_w	=	Maximum bottom velocity due to waves

An example is provided below using the results for the EFDC model grid cell along the western berm with the highest computed bed shear stresses due to currents as computed by the EFDC model. In the example, the maximum bed shear stress due to flows computed by the model are added to the computed bed shear stresses due to waves, and a stable particle size is determined based on those stresses. The stable particle size is computed for the 25-year and 100-year return-interval flow events conservatively assuming that the 100-year return-interval wave occurs at the same time as these events.

For the 25-year return-interval flow event, the computed bed shear stress is 19.1 Pascals (0.399 pounds per square foot [psf]) for the model grid cell. For the 100-year return-interval flow event, the computed bed shear stress is 14.8 Pascals (0.309 psf) for the model grid cell.

The bottom friction coefficient for waves is computed using the following equation (van Rijn 1993):

$$C_{f,w} = 0.045 \left(\frac{u_w A_w}{\upsilon}\right)^{-0.2} \tag{1-3}$$

where:

$C_{f,w}$	=	Bottom friction coefficient for waves
u_w	=	Maximum bottom velocity due to waves
A_w	=	Peak orbital excursion
ν	=	Kinematic viscosity of water

Maximum bottom velocities and peak orbital excursions for the 100-year return-interval wave were computed with water depths over the western berm set equivalent to the 25-year and 100-year return-interval flow events using the Linear Wave Theory Module in ACES. Based on this analysis, the estimated bed shear stress due to waves is 5.39 Pascals (0.113 pcf) for the 25-year event and 0.581 Pascals (0.0121 pcf) for the 100-year event. The shear stresses due to waves are higher for the 25-year return-interval flow event as compared with the 100-year return-interval flow event because the water depths over the berm are lower. Table 4-2 summarizes the results of this analysis.

The stable median diameter (D_{50}) for particles subject to a given shear stress can be estimated based on the approach described by Shields (1936). The correlation between shear stress and particle size presented below represents the point at which the subject particle begins to move or "rock" on the bed and does not necessarily imply significant transport of particles of this size. In addition, Shields' work is based on a bed of uniform particles and does specifically account for the increased stability resulting from a well-graded armor layer constructed from a range of angular particles, thus the use of the Shields model is conservative compared to actual conditions at the site.

$$\tau_{*c} = \frac{\tau_c}{(\gamma_s - \gamma) D_{50}} \tag{1-4}$$

where:

τ_{*c}	=	Critical shear stress parameter (pcf)
τ_c	=	Critical shear stress (threshold of motion; pcf)
γ_s	=	Specific weight of the particle (pcf)
γ	=	Specific weight of the water
D_{50}	=	Median particle size (feet)

Shields provides a plot of dimensionless critical shear stress versus a dimensionless Reynolds number. This graphical representation, commonly known as the Shields diagram, is widely used to determine a general relationship for incipient motion. Rouse (1939) fitted a mean curve to the zone of these data points, above which particles are considered to be in motion, and showed that at higher values of the Reynolds number (i.e., coarse sediments/larger grain sizes, and/or fully turbulent flow), the critical shear stress parameter approaches a constant value of 0.060. Since then, others have proposed more conservative values for the critical shear stress parameter, ranging from 0.039 by Laursen (1963) to 0.045 by Yalin and Karahan (1979).

Rearranging Equation 1-4 above to solve for median particle size, and substituting a specific weight of 165 pcf for natural materials such as the Armor Cap D materials (and assuming that the wave event occurs during a freshwater flow event) and a conservative critical shear stress parameter of 0.039, yields the following relationship:

$$D_{50} = \frac{\tau}{4} \quad (1\text{-}5)$$

The maximum combined bed shear stresses for combined waves and currents for the 25-year and 100-year return-interval events are 0.511 pcf and 0.322 pcf, respectively. The median particle size (D_{50}) to resist the combined waves and currents ranges between 1.0 and 1.5 inches using this method, which is substantially lower than the median particle size of 10 inches for Armor Cap D material.

Table 4-2

Summary of Combined Forces from Currents and Waves

Flood Flow Return-Interval	Forces from Currents			Forces from Waves					Combined Forces	
	Maximum Depth-Averaged Velocity Computed by EFDC Model (m/s)	Maximum Shear Stress Computed by EFDC Model (Pa)	Maximum Shear Stress Computed by EFDC Model (psf)	Peak Orbital Velocity Computed in ACES (m/s)	Peak Orbital Excursion Computed in ACES (meters)	$C_{f,w}$	Computed Shear Stress For Waves (Pa)	Computed Shear Stress For Waves (psf)	Combined Shear Stress due to Waves and Currents (Pa)	Combined Shear Stress due to Waves and Currents (psf)
25-year	2.03	19.1	0.399	0.725	0.248	0.0102	5.39	0.113	24.5	0.511
100-year	2.15	14.8	0.309	0.180	0.0610	0.0179	0.581	0.0121	15.4	0.322

Notes:
ACES = Automated Coastal Engineering System
$C_{f,w}$ = Bottom friction coefficient for waves
m/s= meters per second
Pa = Pascals
psf = pounds per square foot

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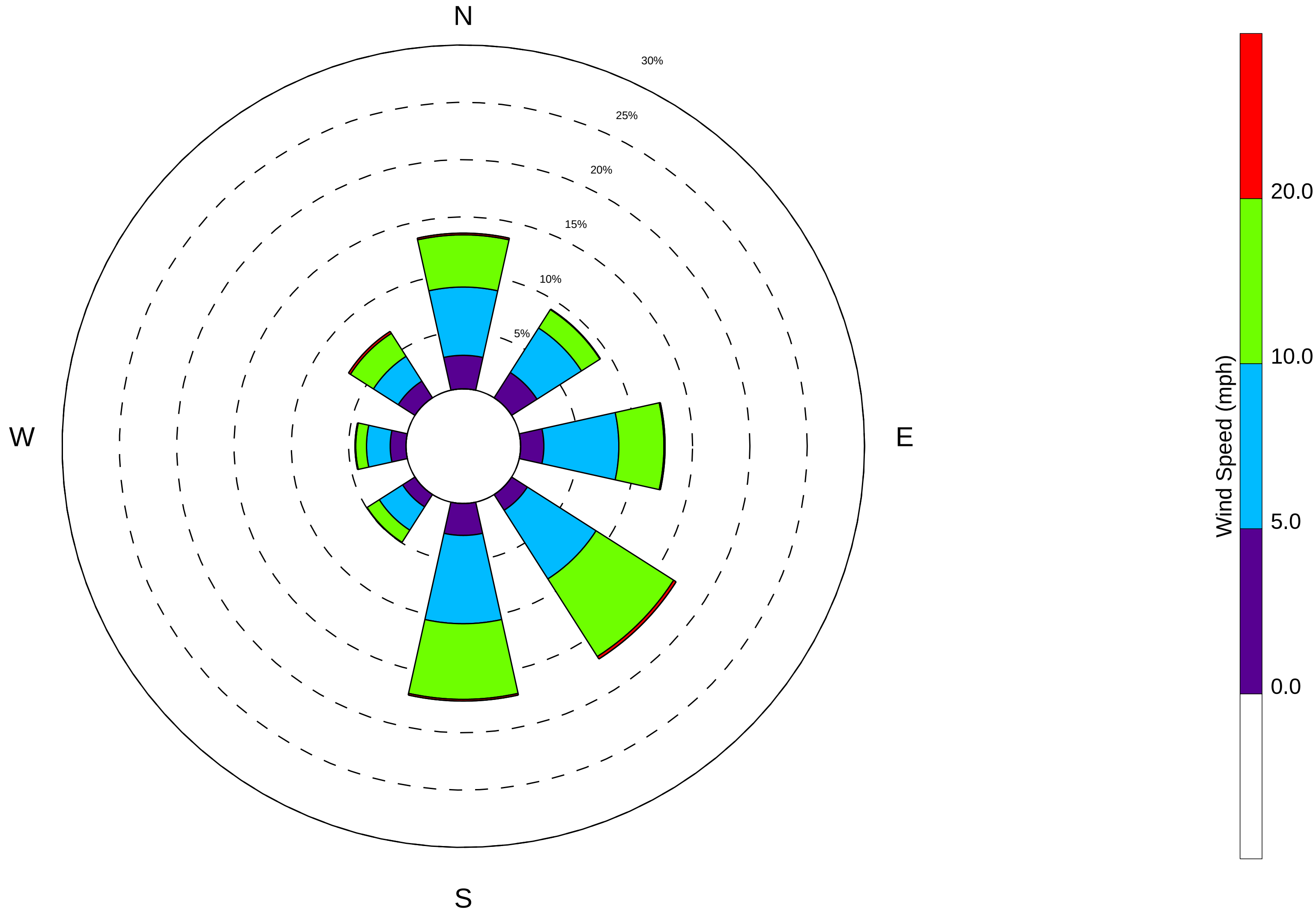
FIGURES



Maximum Recorded Wind Speed: 63.3 mph

Calm Winds 14.07%

Figure 1

Wind Rose Diagram

Draft Feasibility Study - Appendix B: Hydrodynamic Cap Modeling

San Jacinto River Waste Pits Superfund Site

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Figure 2
Fetch Distances
Draft Feasibility Study - Appendix B: Hydrodynamic Cap Modeling
San Jacinto River Waste Pits Superfund Site

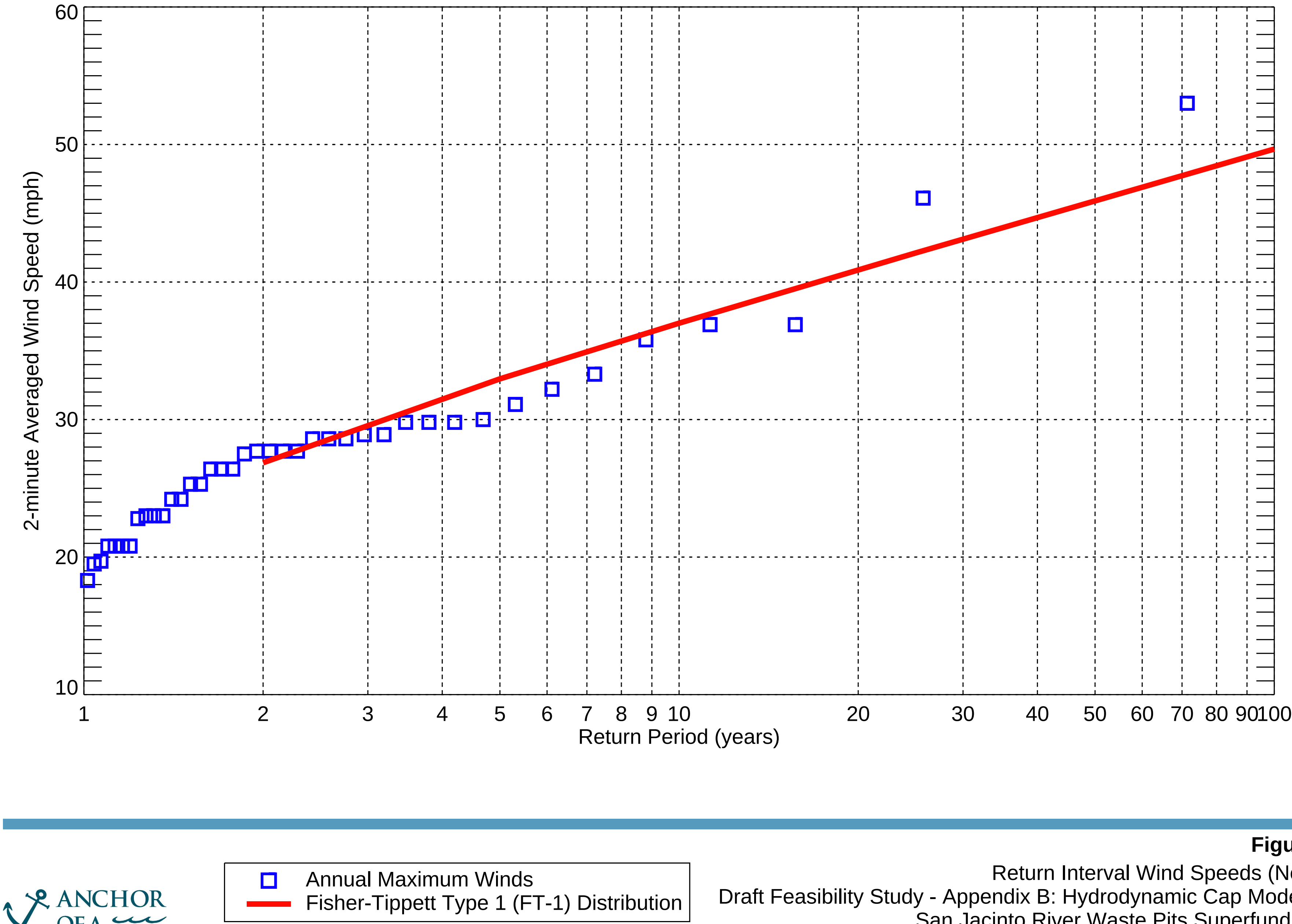

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Figure 3

Return Interval Wind Speeds (North)
Draft Feasibility Study - Appendix B: Hydrodynamic Cap Modeling
San Jacinto River Waste Pits Superfund Site

The wind record is from 1973 to 2012 at the George Bush Intercontinental Airport.

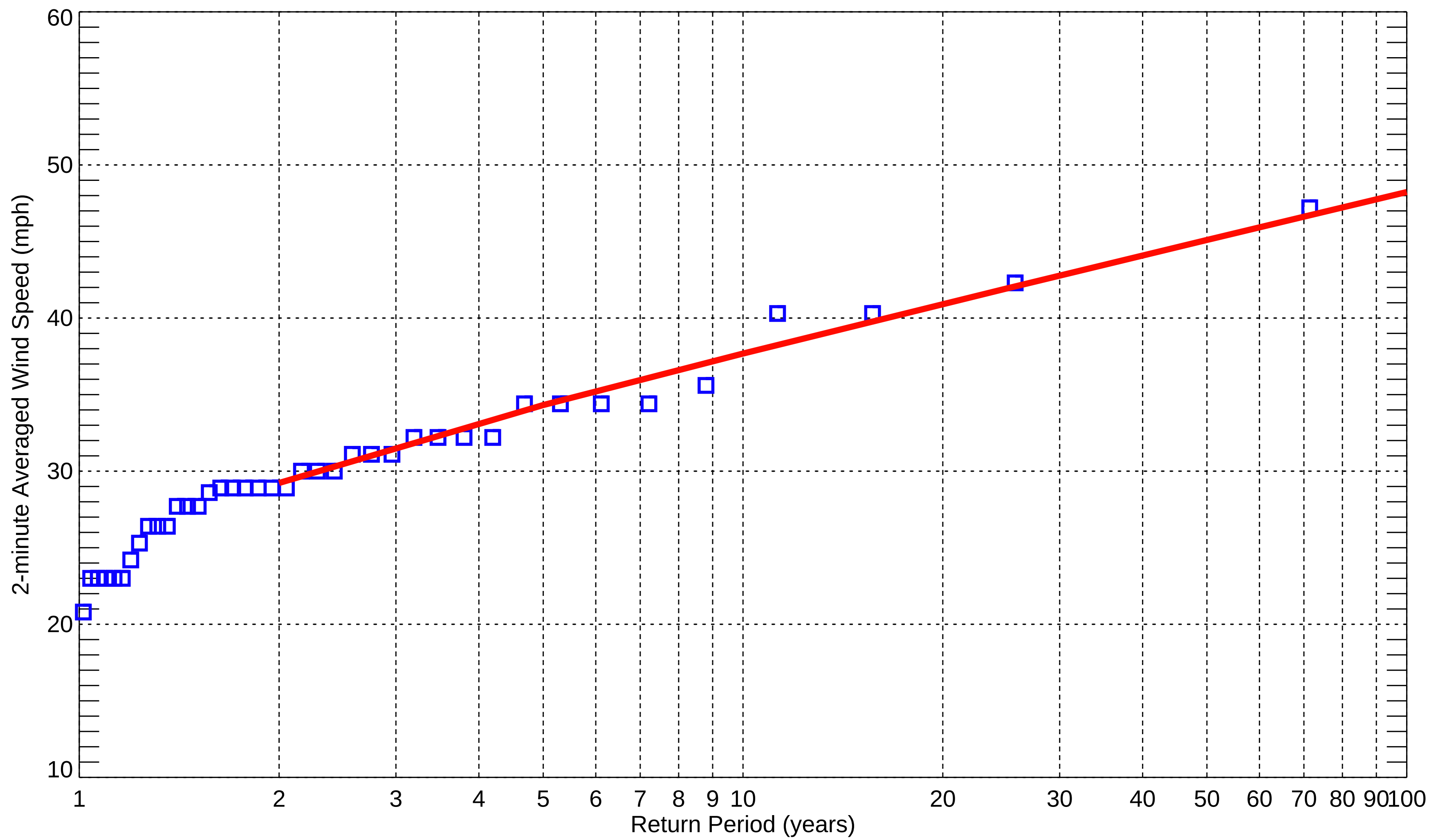

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Figure 4

Return Interval Wind Speeds (Northwest)
Draft Feasibility Study - Appendix B: Hydrodynamic Cap Modeling
San Jacinto River Waste Pits Superfund Site

The wind record is from 1973 to 2012 at the George Bush Intercontinental Airport.

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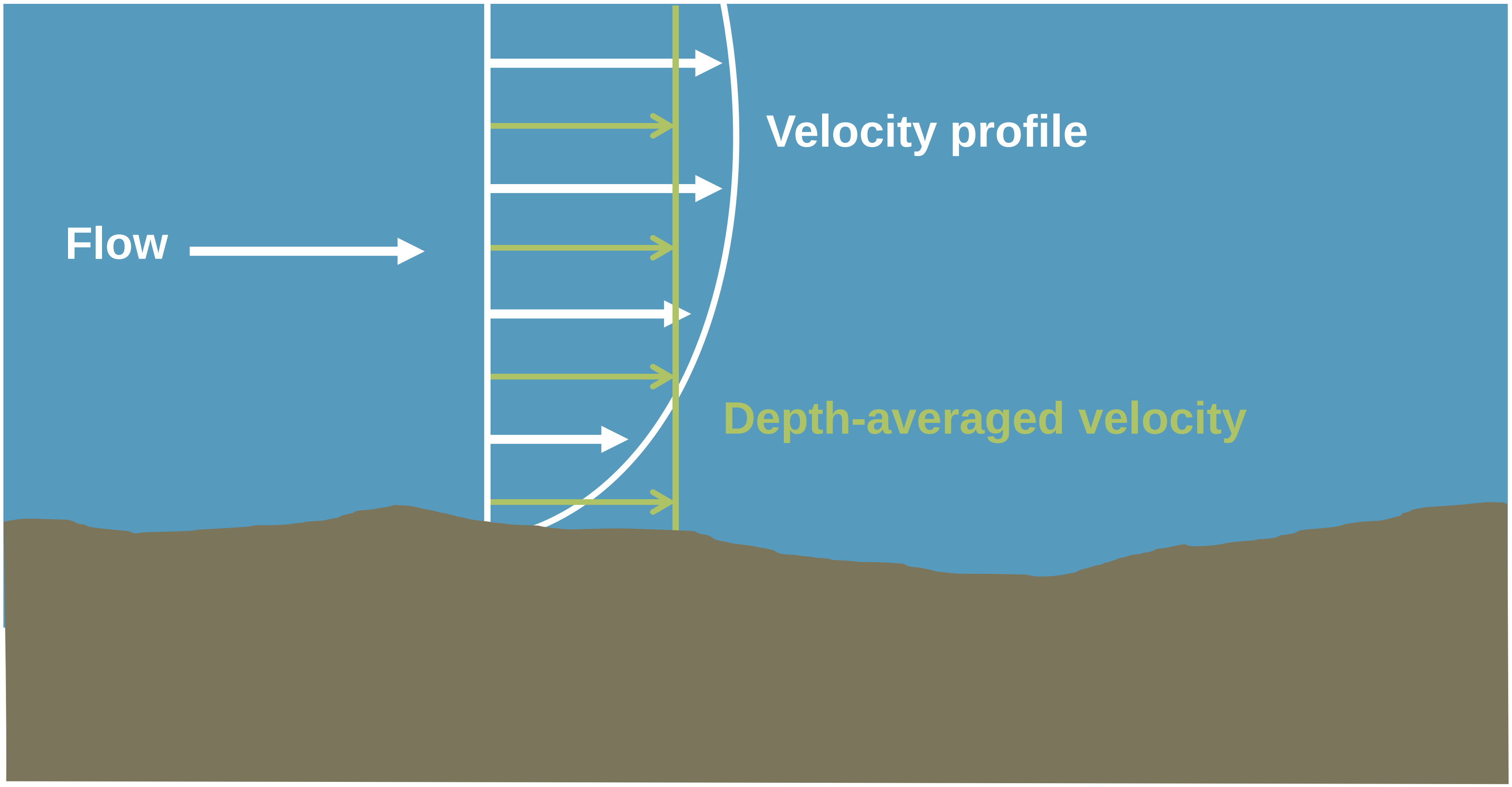

Figure 5
Depth-averaged Velocity Description
Draft Feasibility Study - Appendix B: Hydrodynamic Cap Modeling
San Jacinto River Waste Pits Superfund Site

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Figure 6
High-Flow Simulation Plot Locations
Draft Feasibility Study - Appendix B: Hydrodynamic Cap Modeling
San Jacinto River Waste Pits Superfund Site

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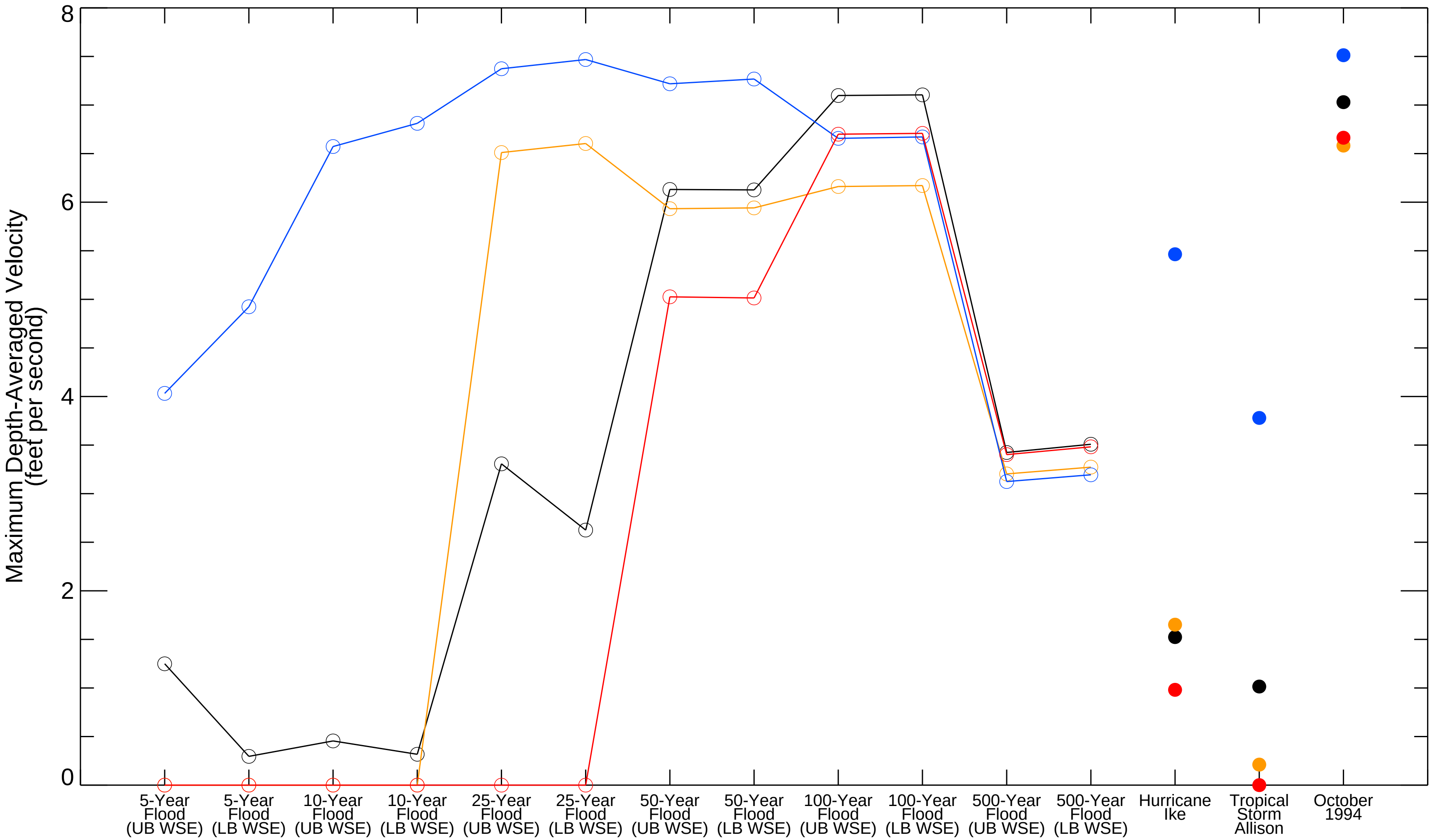

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Figure 7

Maximum Depth-Averaged Velocity During High-Flow Simulations
Draft Feasibility Study - Appendix B: Hydrodynamic Cap Modeling
San Jacinto River Waste Pits Superfund Site

Note: The water surface elevations at the downstream boundary are denoted with UB WSE and LB WSE to represent upper-bound and lower-bound conditions, respectively.

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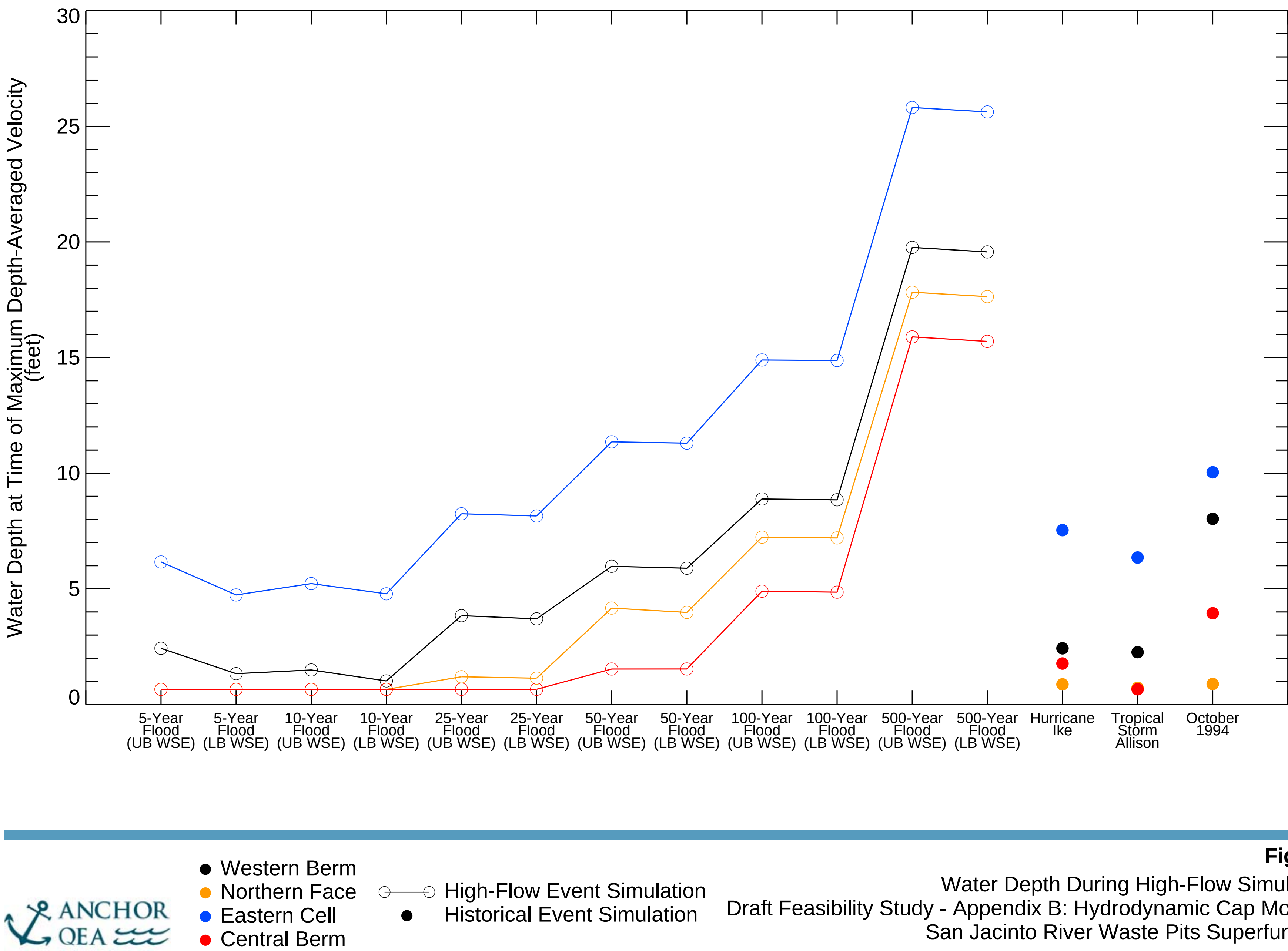

Figure 8

Water Depth During High-Flow Simulations

Draft Feasibility Study - Appendix B: Hydrodynamic Cap Modeling

San Jacinto River Waste Pits Superfund Site

Note: The water surface elevations at the downstream boundary are denoted with UB WSE and LB WSE to represent upper-bound and lower-bound conditions, respectively.

DRAFT FEASIBILITY STUDY REPORT APPENDIX C: REMEDIAL ALTERNATIVE COST DEVELOPMENT

SAN JACINTO RIVER WASTE PITS SUPERFUND SITE

SAN JACINTO FEASIBILITY STUDY ALTERNATIVES								
	ALT 1	**ALT 2**	**ALT 3**	**ALT 4**	**ALT 5a**	**ALT 5b**	**ALT 6a**	**ALT 6b**
Elements:	- TCRA Cap OMM	- Institutional Controls - MNR - TCRA Cap OMM	- Institutional Controls - MNR - Permanent Cap - Permanent Cap OMM	- Institutional Controls - MNR - Permanent Cap - Partial Solidification - Permanent Cap OMM	- Institutional Controls - MNR - Permanent Cap - Partial Removal; Disposal - Permanent Cap OMM	- Institutional Controls - MNR - Permanent Cap - Partial Removal; Incinerate - Permanent Cap OMM	- Institutional Controls - MNR - Full Removal; Disposal	- Institutional Controls - MNR - Full Removal; Incinerate
CONSTRUCTION ITEMS								
Mobilization/Demobilization and Setup								
Mobilization/Demobilization			$ 118,000	$ 920,000	$ 2,180,000	$ 11,630,000	$ 10,340,000	$ 63,730,000
Environmental Protection and Erosion Control			$ 50,000	$ 100,000	$ 200,000	$ 200,000	$ 200,000	$ 200,000
Construction, Payment and As-Built Surveys			$ 50,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000
Construction Materials Testing			$ 15,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000
Silt Curtain					$ 100,000	$ 100,000	$ 100,000	$ 100,000
Permanent Cap Construction								
Additional Armor Rock Placement			$ 671,000	$ 671,000	$ 671,000	$ 671,000		
Treatment								
Temporary Sheet Pile Installation				$ 520,000				
In Situ Solidification				$ 1,599,000				
Sheet Pile Dewatering				$ 535,000				
Excavation and Disposal								
Upland TCRA Cap Excavation				$ 275,000	$ 275,000	$ 275,000	$ 275,000	$ 275,000
Inwater TCRA Cap Excavation				$ 196,000	$ 196,000	$ 196,000	$ 1,957,000	$ 1,957,000
Land-based Sediment Excavation					$ 556,000	$ 556,000	$ 556,000	$ 556,000
Water-based Sediment Excavation/Dredging					$ 322,000	$ 322,000	$ 9,582,000	$ 9,582,000
TCRA Cap Wash Water Treatment & Disposal				$ 155,000	$ 155,000	$ 155,000	$ 540,000	$ 540,000
Offsite Haul & Disposal of TCRA Cap (Subtitle D)				$ 682,000	$ 682,000	$ 682,000	$ 2,376,000	$ 2,376,000
Stabilization of Sediment prior to Shipment					$ 210,000	$ 210,000	$ 6,249,000	$ 6,249,000
Offsite Incineration & Disposal of Sediment						$ 67,140,000		$ 379,350,000
Offsite Haul & Disposal of Sediment (Subtitle C)					$ 8,243,000		$ 46,576,000	
Offsite Haul & Disposal of Sediment (Subtitle D)						$ 4,103,000		$ 23,183,000
Dredge Residuals Cover/Backfill					$ 1,599,000	$ 1,599,000	$ 477,000	$ 477,000
Permanent Cap Replacement								
Replacement Cap Geotextile				$ 83,000	$ 83,000	$ 83,000		
Replacement Cap Armor Stone A				$ 665,000	$ 665,000	$ 665,000		
Replacement Cap Armor Stone C/D				$ 550,000	$ 550,000	$ 550,000		
NON-CONSTRUCTION COST ITEMS								
Engineering Design			$ 150,000	$ 250,000	$ 300,000	$ 300,000	$ 300,000	$ 300,000
Construction Administration/Observation			$ 150,000	$ 250,000	$ 300,000	$ 300,000	$ 300,000	$ 300,000
Long Term Costs								
Long Term Cap Monitoring	$ 500,000	$ 500,000	$ 500,000	$ 500,000	$ 500,000	$ 500,000		
Long Term Natural Recovery Monitoring	$ -	$ 200,000	$ 200,000	$ 200,000	$ 200,000	$ 200,000	$ 200,000	$ 200,000
Long Term Cap Maintenance	$ 450,000	$ 450,000	$ 225,000	$ 225,000	$ 225,000	$ 225,000		
TOTAL OPINION OF PROBABLE COST								
Subtotal (Construction + Non-Construction)	$ 1,000,000	$ 1,200,000	$ 2,200,000	$ 8,600,000	$ 18,300,000	$ 90,700,000	$ 80,100,000	$ 489,500,000
Contingency (30%)	$ 300,000	$ 400,000	$ 700,000	$ 2,600,000	$ 5,500,000	$ 27,200,000	$ 24,000,000	$ 146,900,000
TOTAL Opinion of Probable Cost	**$ 1,300,000**	**$ 1,600,000**	**$ 2,900,000**	**$ 11,200,000**	**$ 23,800,000**	**$ 117,900,000**	**$ 104,100,000**	**$ 636,400,000**

DRAFT

Client: IPC & MIMC
Project: San Jacinto Feasibility Study
Project No.: 090557-01.03

Prepared by: Renee Robertson
Date: 08-30-13
Reviewed by: John Laplante

Engineer's Estimate of Project Quantities & Probable Cost Worksheet
Alternative 1 and 2 - Institutional Controls, MNR, and OMM

Item	Description	Plan Qty.	Unit	Unit Price	Total
CONSTRUCTION LUMP SUM ITEMS					
0001	Mobilization/Demobilization	0	LS	$ -	$ -
0002	Environmental Protection and Erosion Control	0	LS	$ 100,000.00	$ -
0003	Construction, Payment and As-Built Surveys	0	LS	$ 100,000.00	$ -
0004	Construction Materials Testing	0	LS	$ 15,000.00	$ -
Subtotal (Construction Lump Sum Items):					$ -
CONSTRUCTION UNIT COST ITEMS					
0005	Additional Armor Rock Placement	0	TON	$ 110.00	$ -
Subtotal (Construction Unit Cost Items):					$ -
CONSTRUCTION TOTAL:					$ -
ROUNDED TOTAL:					**$ -**
NON-CONSTRUCTION COSTS					
0006	Engineering Design	1	LS	10%	$ -
0007	Construction Administration/Observation	1	LS	10%	$ -
0008	Long Term Cap Monitoring	20	EA	$ 25,000.00	$ 500,000.00
0009	Long Term Natural Recovery Monitoring	0	EA	$ 40,000.00	$ -
0010	Cap Maintenance	6	LS	$ 75,000.00	$ 450,000.00
NON-CONSTRUCTION TOTAL:					$ 950,000.00
PROJECT TOTAL					$ 950,000.00
PROJECT ROUNDED TOTAL:					**$ 1,000,000.00**
30% Contingency					**$ 1,300,000.00**

DRAFT

Client: IPC & MIMC
Project: San Jacinto Feasibility Study
Project No.: 090557-01.03

Prepared by: Renee Robertson
Date: 08-30-13
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Engineer's Estimate of Project Quantities & Probable Cost Worksheet
Alternative 1 and 2 - Institutional Controls, MNR, and OMM

Item	Description	Plan Qty.	Unit	Unit Price	Total
CONSTRUCTION LUMP SUM ITEMS					
0001	Mobilization/Demobilization	0	LS	$ -	$ -
0002	Environmental Protection and Erosion Control	0	LS	$ 100,000.00	$ -
0003	Construction, Payment and As-Built Surveys	0	LS	$ 100,000.00	$ -
0004	Construction Materials Testing	0	LS	$ 15,000.00	$ -
Subtotal (Construction Lump Sum Items):					*$* -
CONSTRUCTION UNIT COST ITEMS					
0005	Additional Armor Rock Placement	0	TON	$ 110.00	$ -
Subtotal (Construction Unit Cost Items):					*$* -
CONSTRUCTION TOTAL:					$ -
ROUNDED TOTAL:					**$ -**
NON-CONSTRUCTION COSTS					
0006	Engineering Design	1	LS	10%	$ -
0007	Construction Administration/Observation	1	LS	10%	$ -
0008	Long Term Cap Monitoring	20	EA	$ 25,000.00	$ 500,000.00
0009	Long Term Natural Recovery Monitoring	5	EA	$ 40,000.00	$ 200,000.00
0010	Cap Maintenance	6	LS	$ 75,000.00	$ 450,000.00
NON-CONSTRUCTION TOTAL:					$ 1,150,000.00
PROJECT TOTAL					$ 1,150,000.00
PROJECT ROUNDED TOTAL:					**$ 1,200,000.00**
30% Contingency					**$ 1,560,000.00**

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Client: IPC & MIMC
Project: San Jacinto Feasibility Study
Project No.: 090557-01.03

Prepared by: Renee Robertson
Date: 08-30-13
Reviewed by: John Laplante

Engineer's Estimate of Project Quantities & Probable Cost Worksheet
Alternative 3 - Permanent Cap

Item	Description	Plan Qty.	Unit	Unit Price		Total	
CONSTRUCTION LUMP SUM ITEMS							
0001	Mobilization/Demobilization	1	LS	$	118,000.00	$	118,000.00
0002	Environmental Protection and Erosion Control	1	LS	$	50,000.00	$	50,000.00
0003	Construction, Payment and As-Built Surveys	1	LS	$	50,000.00	$	50,000.00
0004	Construction Materials Testing	1	LS	$	15,000.00	$	15,000.00
Subtotal (Construction Lump Sum Items):						*$*	*233,000.00*
CONSTRUCTION UNIT COST ITEMS							
0005	Additional Armor Rock Placement	6,100	TON	$	110.00	$	671,000.00
Subtotal (Construction Unit Cost Items):						*$*	*671,000.00*
CONSTRUCTION TOTAL:						$	904,000.00
ROUNDED TOTAL:						**$**	**1,000,000.00**
NON-CONSTRUCTION COSTS							
0006	Engineering Design	1	LS		150,000.00	$	150,000.00
0007	Construction Administration/Observation	1	LS		150,000.00	$	150,000.00
0008	Long Term Cap Monitoring	20	EA	$	25,000.00	$	500,000.00
0009	Long Term Natural Recovery Monitoring	5	EA	$	40,000.00	$	200,000.00
0010	Cap Maintenance	3	LS	$	75,000.00	$	225,000.00
NON-CONSTRUCTION TOTAL:						$	1,225,000.00
PROJECT TOTAL						$	2,129,000.00
PROJECT ROUNDED TOTAL:						**$**	**2,200,000.00**
30% Contingency						**$**	**2,860,000.00**

DRAFT

Client: IPC & MIMC
Project: San Jacinto Feasibility Study
Project No.: 090557-01.03

Prepared by: Renee Robertson
Date: 08-30-13
Reviewed by: John Laplante

Engineer's Estimate of Project Quantities & Probable Cost Worksheet
Alternative 4 - Partial Solidification

Item	Description	Plan Qty.	Unit	Unit Price	Total
CONSTRUCTION LUMP SUM ITEMS					
0001	Mobilization/Demobilization	1	LS	$ 920,000.00	$ 920,000.00
0002	Environmental Protection and Erosion Control	1	LS	$ 100,000.00	$ 100,000.00
0003	Construction, Payment and As-Built Surveys	1	LS	$ 100,000.00	$ 100,000.00
0004	Construction Materials Testing	2	LS	$ 15,000.00	$ 30,000.00
Subtotal (Construction Lump Sum Items):					*$ 1,150,000.00*
CONSTRUCTION UNIT COST ITEMS					
0005	Additional Armor Rock Placement	6,100	TON	$ 110.00	$ 671,000.00
0006	Remove TCRA Riprap - Land Based	5,000	CY	$ 55.00	$ 275,000.00
0007	Remove TCRA Riprap - Water Based	1,900	CY	$ 103.00	$ 196,000.00
0008	Wash TCRA Riprap; Treat and Dispose	310	TON	$ 500.00	$ 155,000.00
0009	Dispose TCRA Riprap - Subtitle D	12,400	TON	$ 55.00	$ 682,000.00
0010	Temporary Sheet Pile	800	LF	$ 650.00	$ 520,000.00
0011	Sheet Pile Dewatering	107	DAY	$ 5,000.00	$ 535,000.00
0012	In situ Solidification	53,300	CY	$ 30.00	$ 1,599,000.00
0013	Replace Geotextile	20,500	SY	$ 4.05	$ 83,000.00
0014	Replace Armor Rock A	9,000	TON	$ 73.90	$ 665,000.00
0015	Replace Armor Rock C/D	5,000	TON	$ 110.00	$ 550,000.00
Subtotal (Construction Unit Cost Items):					*$ 5,931,000.00*
CONSTRUCTION TOTAL:					$ 7,081,000.00
ROUNDED TOTAL:					**$ 7,100,000**
NON-CONSTRUCTION COSTS					
0016	Engineering Design	1	LS	250,000.00	$ 250,000.00
0018	Construction Administration/Observation	1	LS	250,000.00	$ 250,000.00
0019	Long Term Cap Monitoring	20	EA	$ 25,000.00	$ 500,000.00
0020	Long Term Natural Recovery Monitoring	5	EA	$ 40,000.00	$ 200,000.00
0021	Cap Maintenance	3	LS	$ 75,000.00	$ 225,000.00
NON-CONSTRUCTION TOTAL:					$ 1,425,000.00
PROJECT TOTAL					$ 8,506,000
PROJECT ROUNDED TOTAL:					**$ 8,600,000.00**
30% Contingency					**$ 11,180,000.00**

DRAFT

Client: IPC & MIMC
Project: San Jacinto Feasibility Study
Project No.: 090557-01.03

Prepared by: Renee Robertson
Date: 08-30-13
Reviewed by: John Laplante

Engineer's Estimate of Project Quantities & Probable Cost Worksheet
Alternative 5a - Partial Removal with Haz Waste Disposal

Item	Description	Plan Qty.	Unit	Unit Price		Total	
CONSTRUCTION LUMP SUM ITEMS							
0001	Mobilization/Demobilization	1	LS	$	2,180,550.00	$	2,180,000.00
0002	Environmental Protection and Erosion Control	1	LS	$	200,000.00	$	200,000.00
0003	Construction, Payment and As-Built Surveys	1	LS	$	100,000.00	$	100,000.00
0004	Construction Materials Testing	2	LS	$	15,000.00	$	30,000.00
Subtotal (Construction Lump Sum Items):						*$*	*2,510,000.00*
CONSTRUCTION UNIT COST ITEMS							
0005	Silt Curtain	1	LS	$	100,000.00	$	100,000.00
0006	Additional Armor Rock Placement	6,100	TON	$	110.00	$	671,000.00
0007	Remove TCRA Riprap - Land Based	5,000	CY	$	55.00	$	275,000.00
0008	Remove TCRA Riprap - Water Based	1,900	CY	$	103.00	$	196,000.00
0009	Wash TCRA Riprap; Treat and Dispose	310	TON	$	500.00	$	155,000.00
0010	Dispose TCRA Riprap - Subtitle D	12,400	TON	$	55.00	$	682,000.00
0011	Water-based Excavation/Dredging	7,000	CY	$	46.00	$	322,000.00
0012	Land-based Excavation	46,300	CY	$	12.00	$	556,000.00
0013	Sediment Residuals Cover/Backfill	53,300	CY	$	30.00	$	1,599,000.00
0014	Sediment Stabilization prior to Shipment	7,000	CY	$	30.00	$	210,000.00
0015	Incineration	0	TON	$	900.00	$	-
0016	Haul & Disposal of Sediment to Subtitle C Landfill	74,600	TON	$	110.50	$	8,243,000.00
0017	Replace Geotextile	20,500	SY	$	4.05	$	83,000.00
0018	Replace Armor Rock A	9,000	TON	$	73.90	$	665,000.00
0019	Replace Armor Rock C/D	5,000	TON	$	110.00	$	550,000.00
Subtotal (Construction Unit Cost Items):						*$*	*14,207,000.00*
CONSTRUCTION TOTAL:						$	16,717,000.00
ROUNDED TOTAL:						**$**	**16,800,000.00**
NON-CONSTRUCTION COSTS							
0020	Engineering Design	1	LS	$	300,000	$	300,000.00
0021	Construction Administration/Observation	1	LS	$	300,000	$	300,000.00
0022	Long Term Cap Monitoring	20	EA	$	25,000.00	$	500,000.00
0023	Long Term Natural Recovery Monitoring	5	EA	$	40,000.00	$	200,000.00
0024	Cap Maintenance	3	LS	$	75,000.00	$	225,000.00
NON-CONSTRUCTION TOTAL:						$	1,525,000.00
PROJECT TOTAL						$	18,242,000.00
PROJECT ROUNDED TOTAL:						**$**	**18,300,000.00**
30% Contingency						**$**	**23,790,000.00**

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Client: IPC & MIMC
Project: San Jacinto Feasibility Study
Project No.: 090557-01.03

Prepared by: Renee Robertson
Date: 08-30-13
Reviewed by: John Laplante

Engineer's Estimate of Project Quantities & Probable Cost Worksheet
Alternative 5b - Partial Removal with Incineration

Item	Description	Plan Qty.	Unit	Unit Price	Total
CONSTRUCTION LUMP SUM ITEMS					
0001	Mobilization/Demobilization	1	LS	$ 11,630,550.00	$ 11,630,000.00
0002	Environmental Protection and Erosion Control	1	LS	$ 200,000.00	$ 200,000.00
0003	Construction, Payment and As-Built Surveys	1	LS	$ 100,000.00	$ 100,000.00
0004	Construction Materials Testing	2	LS	$ 15,000.00	$ 30,000.00
Subtotal (Construction Lump Sum Items):					*$ 11,960,000.00*
CONSTRUCTION UNIT COST ITEMS					
0005	Silt Curtain	1	LS	$ 100,000.00	$ 100,000.00
0006	Additional Armor Rock Placement	6,100	TON	$ 110.00	$ 671,000.00
0007	Remove TCRA Riprap - Land Based	5,000	CY	$ 55.00	$ 275,000.00
0008	Remove TCRA Riprap - Water Based	1,900	CY	$ 103.00	$ 196,000.00
0009	Wash TCRA Riprap; Treat and Dispose	310	TON	$ 500.00	$ 155,000.00
0010	Dispose TCRA Riprap - Subtitle D	12,400	TON	$ 55.00	$ 682,000.00
0011	Water-based Excavation/Dredging	7,000	CY	$ 46.00	$ 322,000.00
0012	Land-based Excavation	46,300	CY	$ 12.00	$ 556,000.00
0013	Sediment Residuals Cover/Backfill	53,300	CY	$ 30.00	$ 1,599,000.00
0014	Sediment Stabilization prior to Shipment	7,000	CY	$ 30.00	$ 210,000.00
0015	Incineration	74,600	TON	$ 900.00	$ 67,140,000.00
0016	Haul & Disposal of Sediment to Subtitle D Landfill	74,600	TON	$ 55.00	$ 4,103,000.00
0017	Replace Geotextile	20,500	SY	$ 4.05	$ 83,000.00
0018	Replace Armor Rock A	9,000	TON	$ 73.90	$ 665,000.00
0019	Replace Armor Rock C/D	5,000	TON	$ 110.00	$ 550,000.00
Subtotal (Construction Unit Cost Items):					*$ 77,207,000.00*
CONSTRUCTION TOTAL:					$ 89,167,000.00
ROUNDED TOTAL:					**$ 89,200,000.00**
NON-CONSTRUCTION COSTS					
0020	Engineering Design	1	LS	$ 300,000	$ 300,000.00
0021	Construction Administration/Observation	1	LS	$ 300,000	$ 300,000.00
0022	Long Term Cap Monitoring	20	EA	$ 25,000.00	$ 500,000.00
0023	Long Term Natural Recovery Monitoring	5	EA	$ 40,000.00	$ 200,000.00
0024	Cap Maintenance	3	LS	$ 75,000.00	$ 225,000.00
NON-CONSTRUCTION TOTAL:					$ 1,525,000.00
PROJECT TOTAL					$ 90,692,000.00
PROJECT ROUNDED TOTAL:					**$ 90,700,000.00**
30% Contingency					**$ 117,910,000.00**

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Client: IPC & MIMC
Project: San Jacinto Feasibility Study
Project No.: 090557-01.03

Prepared by: Renee Robertson
Date: 08-30-13
Reviewed by: John Laplante

Engineer's Estimate of Project Quantities & Probable Cost Worksheet
Alternative 6a - Full Removal with Haz Waste Disposal

Item	Description	Plan Qty.	Unit	Unit Price	Total
CONSTRUCTION LUMP SUM ITEMS					
0001	Mobilization/Demobilization	1	LS	$ 10,337,700.00	$ 10,340,000.00
0002	Environmental Protection and Erosion Control	1	LS	$ 200,000.00	$ 200,000.00
0003	Construction, Payment and As-Built Surveys	1	LS	$ 100,000.00	$ 100,000.00
0004	Construction Materials Testing	2	LS	$ 15,000.00	$ 30,000.00
Subtotal (Construction Lump Sum Items):					*$ 10,670,000.00*
CONSTRUCTION UNIT COST ITEMS					
0005	Silt Curtain	1	LS	$ 100,000.00	$ 100,000.00
0006	Additional Armor Rock Placement	0	TON	$ 110.00	$ -
0007	Remove TCRA Riprap - Land Based	5,000	CY	$ 55.00	$ 275,000.00
0008	Remove TCRA Riprap - Water Based	19,000	CY	$ 103.00	$ 1,957,000.00
0009	Wash TCRA Riprap; Treat and Dispose	1,080	TON	$ 500.00	$ 540,000.00
0010	Dispose TCRA Riprap - Subtitle D	43,200	TON	$ 55.00	$ 2,376,000.00
0011	Water-based Excavation/Dredging	208,300	CY	$ 46.00	$ 9,582,000.00
0012	Land-based Excavation	46,300	CY	$ 12.00	$ 556,000.00
0013	Sediment Residuals Cover	15,900	CY	$ 30.00	$ 477,000.00
0014	Sediment Stabilization prior to Shipment	208,300	CY	$ 30.00	$ 6,249,000.00
0015	Incineration	0	TON	$ 900.00	$ -
0016	Haul & Disposal of Sediment to Subtitle C Landfill	421,500	TON	$ 110.50	$ 46,576,000.00
0017	Replace Geotextile	0	SY	$ 4.05	$ -
0018	Replace Armor Rock A	0	TON	$ 73.90	$ -
0019	Replace Armor Rock C/D	0	TON	$ 110.00	$ -
Subtotal (Construction Unit Cost Items):					*$ 68,588,000.00*
CONSTRUCTION TOTAL:					$ 79,258,000.00
ROUNDED TOTAL:					**$ 79,300,000.00**
NON-CONSTRUCTION COSTS					
0020	Engineering Design	1	LS	$ 300,000	$ 300,000.00
0021	Construction Administration/Observation	1	LS	$ 300,000	$ 300,000.00
0022	Long Term Cap Monitoring	0	EA	$ 25,000.00	$ -
0023	Long Term Natural Recovery Monitoring	5	EA	$ 40,000.00	$ 200,000.00
0024	Cap Maintenance	0	LS	$ 75,000.00	$ -
NON-CONSTRUCTION TOTAL:					$ 800,000.00
PROJECT TOTAL					$ 80,058,000.00
PROJECT ROUNDED TOTAL:					**$ 80,100,000.00**
30% Contingency					**$ 104,130,000.00**

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Date: 08-30-13
Reviewed by: John Laplante

Engineer's Estimate of Project Quantities & Probable Cost Worksheet
Alternative 6b - Full Removal with Incineration

Item	Description	Plan Qty.	Unit	Unit Price	Total
CONSTRUCTION LUMP SUM ITEMS					
0001	Mobilization/Demobilization	1	LS	$ 63,731,250.00	$ 63,730,000.00
0002	Environmental Protection and Erosion Control	1	LS	$ 200,000.00	$ 200,000.00
0003	Construction, Payment and As-Built Surveys	1	LS	$ 100,000.00	$ 100,000.00
0004	Construction Materials Testing	2	LS	$ 15,000.00	$ 30,000.00
Subtotal (Construction Lump Sum Items):					*$ 64,060,000.00*
CONSTRUCTION UNIT COST ITEMS					
0005	Silt Curtain	1	LS	$ 100,000.00	$ 100,000.00
0006	Additional Armor Rock Placement	0	TON	$ 110.00	$ -
0007	Remove TCRA Riprap - Land Based	5,000	CY	$ 55.00	$ 275,000.00
0008	Remove TCRA Riprap - Water Based	19,000	CY	$ 103.00	$ 1,957,000.00
0009	Wash TCRA Riprap; Treat and Dispose	1,080	TON	$ 500.00	$ 540,000.00
0010	Dispose TCRA Riprap - Subtitle D	43,200	TON	$ 55.00	$ 2,376,000.00
0011	Water-based Excavation/Dredging	208,300	CY	$ 46.00	$ 9,582,000.00
0012	Land-based Excavation	46,300	CY	$ 12.00	$ 556,000.00
0013	Sediment Residuals Cover	15,900	CY	$ 30.00	$ 477,000.00
0014	Sediment Stabilization prior to Shipment	208,300	CY	$ 30.00	$ 6,249,000.00
0015	Incineration	421,500	TON	$ 900.00	$ 379,350,000.00
0016	Haul & Disposal of Sediment to Subtitle D Landfill	421,500	TON	$ 55.00	$ 23,183,000.00
0017	Replace Geotextile	0	SY	$ 4.05	$ -
0018	Replace Armor Rock A	0	TON	$ 73.90	$ -
0019	Replace Armor Rock C/D	0	TON	$ 110.00	$ -
Subtotal (Construction Unit Cost Items):					*$ 424,545,000.00*
CONSTRUCTION TOTAL:					$ 488,605,000.00
ROUNDED TOTAL:					**$ 488,700,000.00**
NON-CONSTRUCTION COSTS					
0020	Engineering Design	1	LS	$ 300,000	$ 300,000.00
0021	Construction Administration/Observation	1	LS	$ 300,000	$ 300,000.00
0022	Long Term Cap Monitoring	0	EA	$ 25,000.00	$ -
0023	Long Term Natural Recovery Monitoring	5	EA	$ 40,000.00	$ 200,000.00
0024	Cap Maintenance	0	LS	$ 75,000.00	$ -
NON-CONSTRUCTION TOTAL:					$ 800,000.00
PROJECT TOTAL					$ 489,405,000.00
PROJECT ROUNDED TOTAL:					**$ 489,500,000.00**
30% Contingency					**$ 636,350,000.00**

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